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THE EFFECT OF AERIAL BOMBARDMENT OF THE RUHR ON AXIS WAR POTENTIAL

29 July 1943

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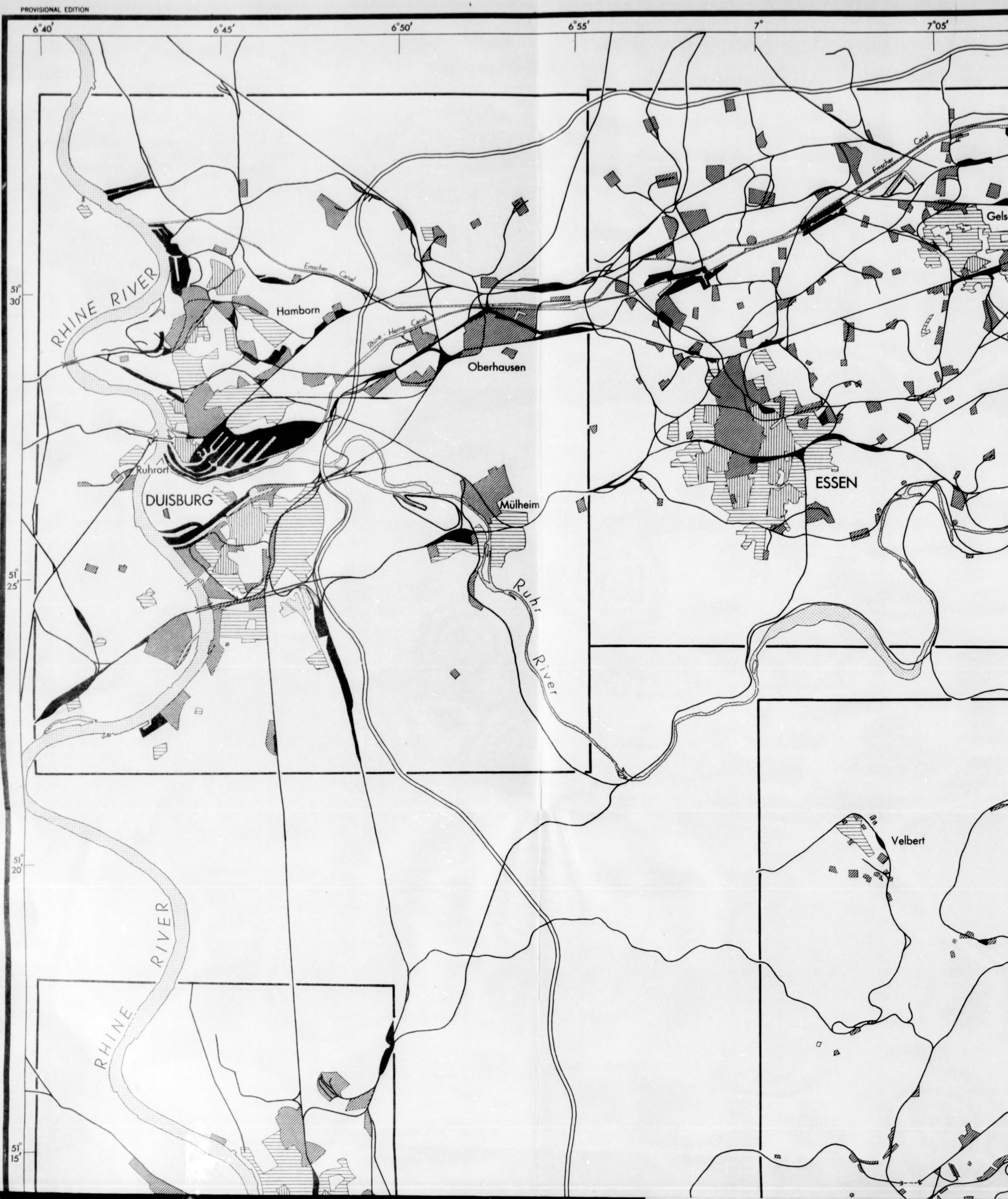
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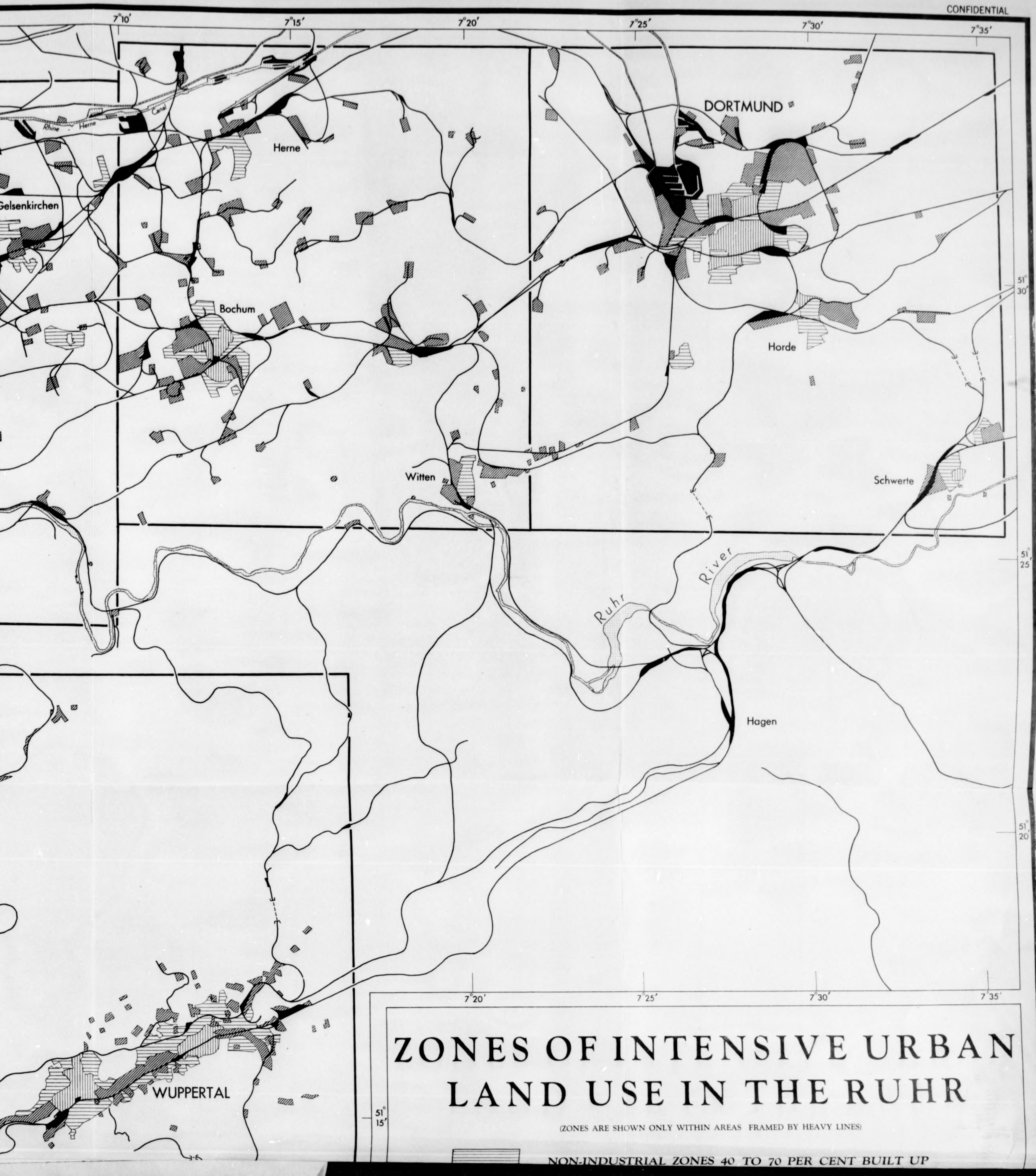
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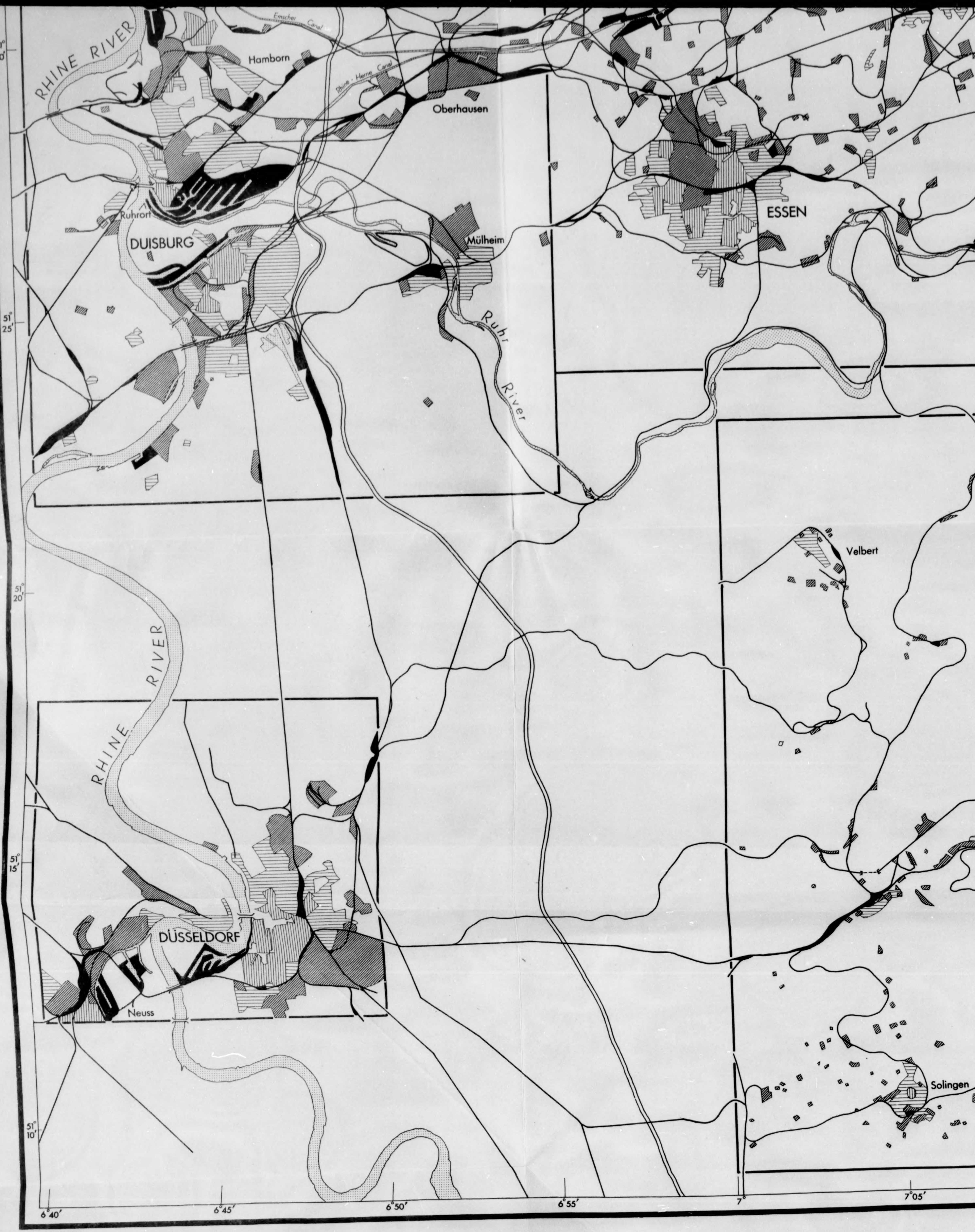
ZONES OF INTENSIVE URBAN LAND USE IN THE RUHR

(ZONES ARE SHOWN ONLY WITHIN AREAS FRAMED BY HEAVY LINES)

▤ NON-INDUSTRIAL ZONES 40 TO 70 PER CENT BUILT UP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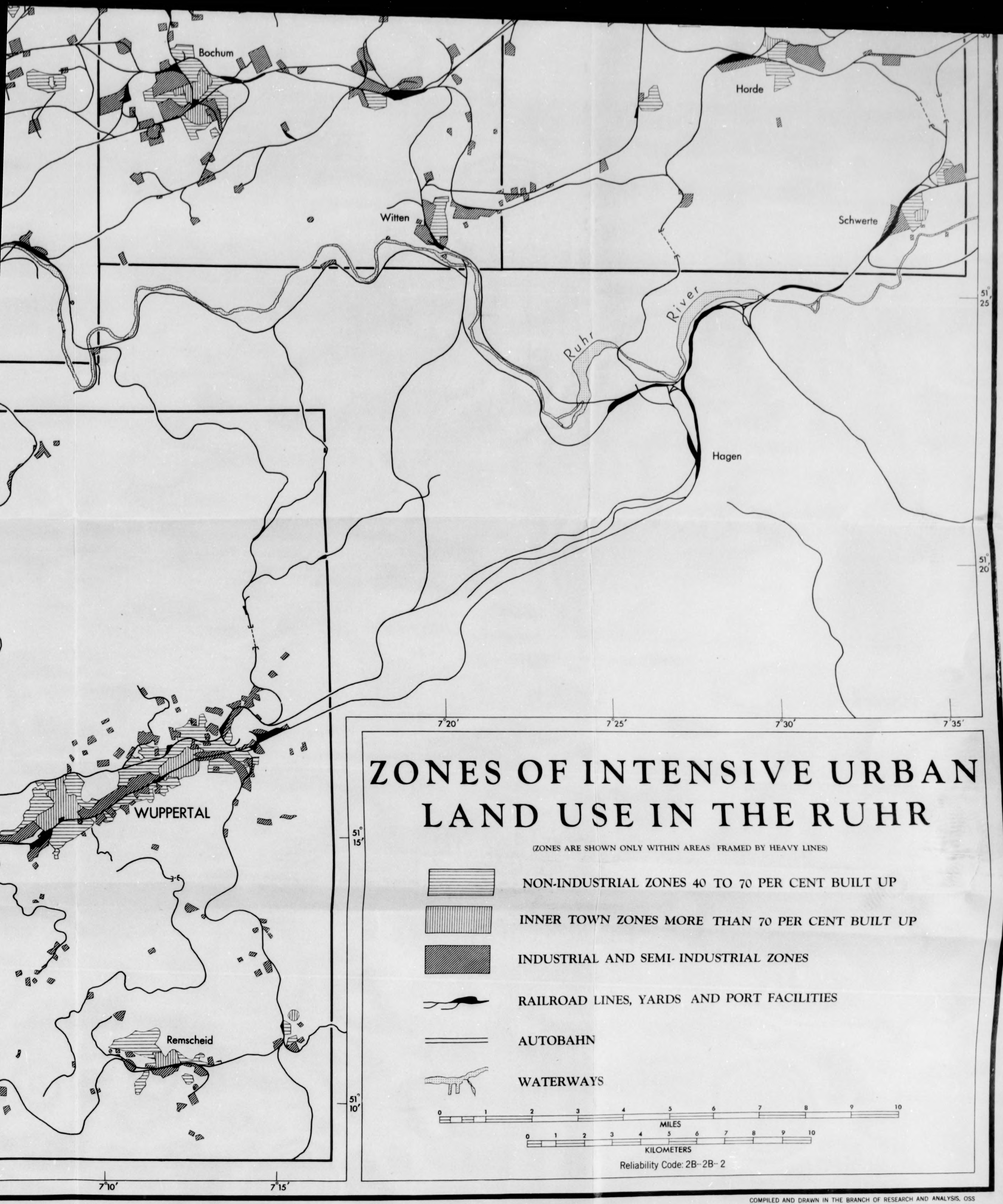
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ZONES OF INTENSIVE URBAN LAND USE IN THE RUHR

(ZONES ARE SHOWN ONLY WITHIN AREAS FRAMED BY HEAVY LINES)

- ▤ NON-INDUSTRIAL ZONES 40 TO 70 PER CENT BUILT UP
- ▥ INNER TOWN ZONES MORE THAN 70 PER CENT BUILT UP
- ▨ INDUSTRIAL AND SEMI- INDUSTRIAL ZONES
- RAILROAD LINES, YARDS AND PORT FACILITIES
- AUTOBAHN
- WATERWAYS

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SUMMARY AND CONCLUSIONS

The Ruhr (excluding Cologne, Krefeld, and Kassel) is responsible for one-quarter or more of the total European Axis output of steel, synthetic rubber, synthetic motor fuel, tungsten carbide, batteries, wire, pipe and tubes, machine tools, heavy machinery, coal and coke; for 30 percent or more of armor plate, engine parts, ammunition, artillery and guns.

A few months ago, the RAF began an intensified campaign of area bombing against the cities of this chief industrial district of Axis Europe. In duration and intensity thus far this campaign is without precedent, and it may be expected to continue on the present scale at least until fall. If it succeeds in putting out of action an important part of Ruhr industry, the offensive capabilities of the German military machine will be seriously curtailed.

This study estimates the damage which may be done to the Ruhr in the third quarter of 1943, and the consequences to German military capabilities. It is assumed that the nature and intensity of the bombing will be about the same as in May and June; that is, that 8,700 tons of bombs will be dropped in area-bombing attacks during each month. Given this premise:

1. Thirty percent of the bombs dropped will fall in built-up areas, achieving an average intensity of 12 tons per square mile per month.

2. As a result, 11 percent of the population of the Ruhr will be forced to abandon their homes. As 18.5 percent of the population is already estimated to have been de-housed, nearly 30 percent of the population will have lost their homes by October 1943. In addition, many houses will have been damaged without actually rendering them uninhabitable.

3. Serious damage to industrial buildings will exceed 540 acres during the quarter. Previous raids have already inflicted such damage to 960 acres; thus by October a total of 1,500 acres, or one-seventh of the total industrial buildings of the Ruhr will have suffered serious damage.

4. Ruhr industry in general will be cut by the end of September to about two-thirds of last year's rate of output, and can be prevented from subsequently recovering, even if the intensity of bombing is somewhat reduced for the winter. The incidence of this reduction of output on various industries will depend in large part on the relative vulnerability, replaceability, importance and transferability of their installations.

5. The principal industries in which production loss will be difficult to replace are high-quality coal, metallurgical coke, high-

quality steel (especially armor plate), and synthetic oil. Evacuation of these industries to less vulnerable parts of Germany will be so difficult that it will probably not be attempted.

6. The remaining industries outstanding in the area - engine parts, pipes and tubes, batteries, ovens and furnaces, tungsten carbide, and steel finishing and processing - can either be moved with relative ease or can be replaced by the expansion of production at other plants.

7. The transfer of labor accompanying the relocation of industry will result in some temporary difficulties.

8. The strain on transportation resulting directly from evacuation of the Ruhr will not be insurmountable, but the additional need for transport occasioned by a scattering of the tightly integrated industrial complex of the Ruhr might be significant.

9. The loss of the Ruhr production would have little immediate effect on military capabilities. Reduced production of synthetic oil might temporarily affect military operations within a matter of months; a lower quality of armor plate and a difficulty in maintaining first-line strength in military vehicles and ammunition stocks would probably be apparent in about a year.

10. In the long run, military requirements at the present level could probably be met, but only by severe restriction of the civilian economy and by permitting deterioration of industrial equipment. Plans for both immediate and future military operations would require review and perhaps curtailment. The expansion of offensive operations would not be likely, but a strong defense could be maintained indefinitely.

THE EFFECT OF AERIAL BOMBARDMENT OF THE RUHR ON AXIS WAR POTENTIAL

The virtues of large-scale aerial bombardment as a softener of Axis Europe have commanded great attention in recent weeks, and it is suggested that an aerial attack can be mounted this year on a scale sufficient to warrant postponement of a land invasion of the mainland of Europe. The implication is that the Axis can be so weakened that a 1944 invasion may assume almost a mop-up character.

This point of view has been encouraged by Mr. Churchill's statement to the Congress that the attempt to break the back of German resistance through aerial bombardment alone is "an experiment well worth trying"; further encouragement has been given by the apparent tactical success of air power in reducing Pantelleria.

Important strategic decisions may hinge on estimates of how successful aerial bombardment can be in reducing the economic war potential of Germany in 1943. The attention of the RAF Bomber Command based on Britain seems at present concentrated on the Ruhr industrial basin, on account of its highly concentrated character and its relative nearness to British bases. An index of the success of such bombardment as a strategic knockout weapon will be the extent to which continued attack leads to curtailment or abandonment of production in the Ruhr.

This memorandum is concerned with the degree of damage that will probably be done in the Ruhr by the end of the third quarter of 1943, and with the consequences to German war potential if aerial attack knocks out a substantial part of Ruhr production.

I. THE AREA

"The Ruhr" is a term loosely applied to the densely settled area of heavy industry in and near the valley of the Ruhr River. The British Air Ministry's series of "Zone Maps of the Ruhr" covers an east-west belt from Duisburg to Dortmund, about 40 miles long and 10 miles wide. For the purposes of the present study, however, it seemed advisable to extend coverage a few miles to the north (including Recklinghausen, Werne, and Lünen), to add the important Düsseldorf and Wuppertal areas on the south, and to adopt the Rhine as the western boundary. Figure I omits the added northern fringe but shows urban zones of all the towns which have been surveyed on that basis by the Air Ministry. Figures 2-7 include the whole area of the Ruhr as here defined.

It would have been better to enlarge the coverage of the study still further to include Krefeld and Cologne, as it now appears that those cities are a part of the general target area under RAF night attack during the present campaign. The general character of the conclusions drawn, however, permits application to this wider area without substantial modification.

If the available bombs are spread over a somewhat larger area, bomb densities and damage rates per acre will be slightly lower; the aggregate damage, however, should be about the same.

The present resident population of the Ruhr as here defined is about 4,600,000, almost entirely urban. The northern part is devoted to coal mining, and the rest to a complex of heavy industry in which steel, chemical, and metal-working plants predominate.

II. PAST AND PROSPECTIVE INTENSITY OF AIR ATTACK

Virtually all bombing operations against the Ruhr thus far have been night area attacks by the RAF. Tables 1 and 2 give a summary of these operations since January 1942.

It will be observed that activity has fluctuated widely, but has trended sharply upward this spring, with more than twice as many aircraft attacking in May as in any previous month. The last two columns of Table 1 indicate that raids are on an increasingly large scale both in planes and in bomb load. In June 1943 the average raid involved 434 planes carrying 3.3 tons each, while the average 1942 raid involved 178 planes with 1.9 tons each. Until May 1943, rather less than half the RAF's night activity was directed at the Ruhr; in May, however, nearly 96 percent of all bombs were dropped there and in June 60 percent.[1]

In attempting to foresee the results of the bombing "experiment" this paper assumes that the RAF will continue to direct the bulk of its night sorties to the Ruhr, maintaining the level of activity reached in recent months. The present pattern involves a rotation of visits among all the major Ruhr cities, with the average raid involving about 1,450 tons of bombs fairly evenly distributed between high explosive bombs (HE) and incendiary bombs (IB). It will be assumed that each month will see the equivalent of six such raids - i.e., about 8,700 tons of bombs - over the Ruhr as a whole.

The duration of this campaign has probably not yet been decided. It would seem likely, however, that sometime this fall there will be a change of pace, probably a slackening. If the experiment is really successful, both we and the enemy will know it by then, and destruction or evacuation will have reduced the Ruhr's strategic significance to a point where other targets may claim attention. On the other hand, if a solid spring and summer of concentrated effort by the RAF failed to produce decisive effects, the experiment is not likely to be prolonged. In that case, we may expect a turn to other targets promising more immediate results, or lacking the formidable anti-aircraft and fighter protection now massed in the Ruhr. Finally, climatic conditions will in any event impose a reduction of activity before the end of the year.

In view of all these considerations, it is appropriate to consider the likely effects of a maintenance of roughly current rates of Ruhr night attack through the third quarter of 1943.

It is further assumed that precision bombing activity in the Ruhr will be negligible, as it has been to date. The blotting-out of a local industrial complex as such is preeminently a job for area-bombing

---

[1] An additional 30 percent were dropped on Cologne and Krefeld in June.

Table 1. SUMMARY OF RAF NIGHT BOMBING OPERATIONS OVER THE RUHR. JANUARY 1942 THROUGH JUNE 1943

Period	Number of Raids	Aircraft Attacking		Bombs Dropped Over Target				Average Size of Raid	
		Number	Percent of RAF night total	HE, tons	IB, tons	Total tons	Percent of RAF night total	Number of aircraft attacking	Tons of bombs
1942									
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	5	653	51.3	870	249	1,119	51.6	131	224
April	5	595	27.4	447	456	903	36.9	119	181
May	0	0	0	0	0	0	0	0	0
June	5	1,170	38.6	733	1,324	2,057	38.2	234	411
July	5	1,319	52.9	1,991	801	2,792	52.2	264	558
August	4	293	20.3	407	295	702	20.2	73	176
September	3	767	33.3	830	767	1,597	32.2	256	532
October	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0
December	1	193	20.2	220	293	513	22.8	193	513
TOTAL 1942	28	4,990	25.7	5,498	4,185	9,683	26.1	178	346
1943									
January	10	493	35.5	813	796	1,609	42.7	49	161
February	0	0	0	0	0	0	0	0	0
March	4	1,235	32.9	1,476	1,607	3,083	32.1	309	771
April	5	1,399	35.5	2,202	1,984	4,186	38.8	280	837
May	6	3,006	95.5	4,647	4,241	8,888	95.7	501	1,481
June[a]	6	2,603	60.0	4,274	4,229	8,503	60.5	434	1,417
FIRST HALF 1943	31	8,736	428	13,412	12,857	26,269	45.6	282	847

---

a. In addition to raids on the Ruhr as defined in this paper, the RAF in June made a night raid on Krefeld and two on Cologne, totalling 1,291 aircraft, 2,181 tons of HE and 2,037 tons of IB.

Table 2. SUMMARY OF RAF NIGHT BOMBING OPERATIONS

OVER THE RUHR, JANUARY 1942 THROUGH JUNE 1943, BY CITIES

Target	1942		First Half 1943		Monthly Average Tonnages	
	Raids	Tons dropped over target	Raids	Tons dropped over target	1942	First Half 1943
ALL RUHR CITIES	28	9,683	31	26,269	807	4,378
Essen	16	4,335	12	5,901	361	984
Duisburg	7	3,238	6	5,050	270	842
Düsseldorf	3	1,838	4	4,481	153	747
Wuppertal	0	0	2	3,449	0	575
Bochum	0	0	3	2,679	0	446
Mülheim	0	0	1	1,539	0	256
Dortmund	2	272	1	1,305	23	218
Gelsenkirchen	0	0	1	1,291	0	215
Oberhausen	0	0	1	574	0	96

night raids, while the most appropriate and effective use of precision bombing, which can select its targets individually, is against industries rather than localities as target systems. Only a small part of the total industry of the Ruhr consists of essential units of high-priority industrial target systems of this character.

III. BOMB DENSITIES ON BUILT-UP AREAS

The amount of physical and economic damage done by dropping bombs over the Ruhr at the rate of 8,700 tons a month depends to a large extent on the accuracy with which those bombs are directed to vulnerable and important targets.

Photo-reconnaissance following past raids in that region has identified between 15 and 30 percent of the bombs dropped in an attack as hits on the built-up area of the target city. These percentages, however, clearly understate the true percentage of hits on built-up area. Over most of the Ruhr, at least a quarter of the area is built up; it is therefore difficult to see how any smaller proportion of hits could be consistently registered without a systematic effort to miss targets. The understatement is explained by the facts that not all HE bombs[1] leave identifiable craters; that the photographic cover is never complete; and that many bombs which miss the target city will hit built-up areas of nearby smaller towns which are not given photographic cover.

In view of these biases and the discernible trend toward improved navigational accuracy, it seems safe to assume that about 30 percent of the bombs dropped in Ruhr attacks will fall in some built-up area.[2] Thus 2,610 tons per month would fall in such areas, yielding an average density of nearly 12 tons per square mile per month.

In night raids an effort is made to concentrate hits in and around city centers and large industrial areas like the Krupp works. Consequently, intensities higher than 12 per square mile per month are to be expected in such zones, while in the suburbs the densities will tend to be lower than 12. The probable relationships will vary according to the individual layouts of Ruhr cities; but a study of bomb plots in several recent raids supports the following assumptions for purposes of general estimate:

---

[1] Photographic identification is in terms of HE only; it may be assumed that the pattern of IB is similar, since both types are aimed at the same points.

[2] This percentage will be applied to 1943 activity and the ratio of 25 percent to the admittedly less accurate bombings of 1942.

Zone	Area in square miles, for all Ruhr cities and towns[1]	Tons of bombs per month (current and prospective rate)[2]	Bomb density (tons per square mile per month)
ALL BUILT UP ZONES	225	2,610	12
Relatively compact non-industrial, more than 40 per-cent built-up	61	1,153	19
Industrial	56	731	13
Suburban non-industrial, less than 40 percent built-up	90	630	7

---

[1] These area estimates are based on fragmentary Air Ministry data for certain Ruhr cities only. They do not quite add up to the 225 miles of built-up area in the Ruhr, because in certain cities the Air Ministry recognizes a fourth class of area ("mixed") which is here disregarded.

[2] The assumed pattern of distribution of bombs among the various zones has been based on such actual bomb plot data as are available for Ruhr cities.

IV. PHYSICAL DAMAGE TO STRUCTURES

Air raid damage is difficult to assess even in physical terms, to say nothing of the loss of productive potential. Reliance must be placed on the measurement of "visible" damage from reconnaissance photographs secured only after certain raids, and much damage is impossible to identify in this way. Hence the accomplishments of particular raids are far from clear. Moreover, since the weights of the individual bombs that did the damage are not known precisely, it is difficult to infer what damage future bombing might do to the same cities. Finally, the few German cities on which raid damage analyses are available[1] may differ somewhat in layout and structure from Ruhr cities in general, so that extension of observed results to whole area is hazardous.

These risks must, however, be taken if any general view of the probable accomplishments of air attack is to be had. This section attempts, therefore, to use the observed results of past raids on Germany together with other information about the effects of bombardment to sketch a picture of the physical damage inflicted in the Ruhr raids. The first part deals with damage to housing and its effects on the population of the Ruhr; the second part with physical damage to industrial structures.

A. Damage to Housing

At the beginning of the aerial offensive of 1942, there were in the Ruhr some 1.35 million dwelling units. These accommodations housed about 4.60 million persons exclusive of those departed for military service. Table 3 summarizes our estimates of the number of dwelling units rendered uninhabitable since 1 January 1942 and of the number of people made homeless.

These figures indicate that, by the end of 1942, that is in the first twelve months of fairly heavy raids, some 55 thousand Ruhr dwellings had been made unlivable. Correspondingly, about 191 thousand persons or 4.2 percent of the Ruhr population lost their houses. The damage done to a few heavily bombed cities was, of course, greater. In Essen, for example, over 15 percent of the dwellings were destroyed and a similar proportion of the population rendered homeless.

The first half of 1943 saw an enormous increase in the weight of RAF raids and in their degree of concentration upon the Ruhr. From January through June 1943, it is estimated that about 167 thousand additional dwellings were made uninhabitable. This additional

---

[1] Essen, Düsseldorf and Saarbrucken. Saarbrücken is not in the Ruhr.

Table 3. ESTIMATES OF NUMBER OF DWELLINGS MADE UNINHABITABLE AND NUMBER OF PERSONS DEHOUSED BY AIR BOMBARDMENT IN THE RUHR

(Figures -- in thousands -- represent cumulative

damage from 1 January 1942 to dates specified)

Target City	To 1/1/43		To 7/1/43		To 8/1/43		To 9/1/43		To 10/1/43	
	Dwellings	Persons	Dwellings	Persons	Dwellings	Persons	Dwellings	Persons	Dwellings	Persons
Essen	27.8	95.9	63.5	219.1	68.6	236.7	77.0	265.7	83.0	286.4
Düsseldorf	11.8	38.5	43.4	142.0	51.0	166.5	58.5	191.0	65.2	213.0
Duisburg	14.7	52.5	39.6	141.4	43.8	156.4	48.0	171.4	52.0	185.6
Wuppertal	-	-	32.8	96.4	38.4	112.9	44.3	130.2	49.0	144.6
Dortmund	1.2	4.1	8.4	28.6	16.5	56.3	24.0	82.0	31.0	105.7
Bochum	-	-	16.3	55.0	21.0	70.7	24.5	82.6	28.0	94.3
Gelsenkirchen	-	-	9.7	35.0	14.1	50.9	18.1	65.3	22.4	80.9
Mülheim	-	-	6.9	23.0	10.2	34.0	10.7	35.6	12.6	42.0
Oberhausen	-	-	2.7	10.0	5.8	21.6	8.2	30.5	10.5	39.1
ALL RUHR CITIES	55.5	191.0	223.3	750.6	269.4	906.0	313.3	1,054.3	353.7	1,191.6
ALL RUHR CITIES -- percentages of total dwellings rendered uninhabitable and population dehoused	4.1	4.2	16.5	16.3	20.0	19.7	23.2	22.9	26.2	25.9

destruction accounted for about 12 percent of the Ruhr's original complement of housing. It also forced an additional 12 percent of the population out of their homes.

As indicated in Section II above, it can be expected that the rate of attack will continue for some time at about double the average established during the first six months of 1943. At that rate, by 1 August it is estimated that a total of 20 percent of Ruhr dwellings will have been rendered uninhabitable and that a similar proportion of the population -- more than 900,000 persons -- will have been forced to find new homes. By 1 September, nearly 23 percent of the population will have been dehoused, and by 1 October, nearly 26 percent, or 1,200,000 persons.

These totals do not tell the whole story of damage to Ruhr housing. The procedure of estimate assumes a diminution in the destructive effect of successive raids as more and more houses are eliminated, and does not allow for possible construction of replacement dwellings (such as emergency barracks) which are then exposed to attack. Estimates of houses destroyed include only houses in existence at the beginning of 1942. Some few of the persons dehoused may be bombed out more than once, but counted only once in the estimates.

Furthermore, many houses not rendered uninhabitable have been and will be damaged enough to cause injury, shock or inconvenience to their occupants. Repairs to these houses involve a not inconsiderable drain on enemy resources.

In calculating the effect of bombing on Ruhr housing, the first step was to estimate the "vulnerable areas" of HE and IB. The vulnerable area of a bomb is defined as the area within which damage of a specified degree may be presumed to be done to all structures. In the case of housing, the degree of damage involved is that sufficient to make a dwelling uninhabitable ("serious" damage in the terminology of the British Ministry of Home Security reports). Information required to calculate the magnitude of vulnerable areas so defined was available from reports both of destruction observed in German cities after a raid and of the detailed examination of recognizable incidents of particular bombs in England.

On the basis of these data, the areas vulnerable to "serious" housing damage from British bombs were estimated to be 1.2 acres from HE and 3.5 acres for IB. Calculation of housing damage from the weight of bombs dropped on various targets and estimated vulnerable areas was carried through for individual cities, with estimated total tonnage to be dropped during the third quarter of 1943 pro-rated among the various important Ruhr targets on the basis of their built-up areas.

The method of estimate used allows for the overlap of areas of destruction in successive raids and the consequent tendency toward diminishing returns. This tendency is naturally more pronounced in the case of IB. Not only are there fewer unburned structures left to hit after successive raids, but the spread of fires is retarded by the gaps resulting from previous destruction. In the first of a series of three recent raids on Essen, for example, IB was over six times as effective (ton for ton) as HE in causing visible damage, and in the second raid, twice as effective; while in the third raid IB and HE showed approximately equal effectiveness.

B. Damage to Industrial Buildings

Physical destruction done to industrial structures has been estimated by methods similar to those used for housing. In the case of industrial buildings, however, the degree of damage in terms of which vulnerable areas were calculated was that visible in aerial photographs.

Estimates so derived indicate that by the end of June 1943, some 750 acres of industrial structures had suffered visible damage. The summer campaign will probably raise this total by 60 percent if pursued through the third quarter of the year. By the end of September at this rate, it could be expected that the area of visible damage to industrial buildings would be about 1,200 acres, or more than one-eighth of the total industrial buildings of the Ruhr.

C. Diversion of Resources to Repair of Structural Damage

The repair and replacement of damaged factories, machinery, stocks, and houses constitutes an important drain on enemy resources of manpower and materials. The assessment of this drain is extremely difficult, because a substantial part of the repair work is done by labor which would not otherwise be productively engaged, and because much of the damage is inflicted on non-essential structures whose repair can be postponed until after the war.

The order of magnitude of the drain on resources can, however, be gauged by an analysis of the results of the April-May raids on Essen. The British Ministry of Home Security estimates that the repair of damage to industrial structures, plant, and machinery, and the replacement of industrial stocks would require 34 million man-hours of labor, not counting labor in the factories which could be used for clearance and repair because of stoppages of production. It further estimates that repairs to damaged (but not demolished) houses and the replacement of a minimum of household goods (£50) in demolished houses would require an additional 32 million man-hours. Sixty-six million man-hours are the equivalent of a little over one month of work for the 300,000 working population of Essen.

This is a very high figure, exceeding the estimated loss of man-hours in industrial production in Essen by about 50 percent. Undoubtedly the strain on the Axis economy imposed by the necessity of repairing or replacing material damage is one of the most important consequences of strategic bombing. It must be remembered, however:

(a) that the labor required to repair material damage is, on the whole, less valuable than labor employed in war production;

(b) much of the damage need not be repaired;

(c) there is an increasing tendency to require workers to repair their own houses in their off-time; and

(d) the incidence of the drain on labor is widely diffused over Axis Europe, and may be directed wherever labor is most abundant.

V. PRODUCTION LOSS IN THE RUHR

Any appraisal of the probable loss of production from bomb damage in the Ruhr must rest as yet on a very slender basis.

It is possible, however, to reach some judgment as to the order of magnitude of this loss by consulting the experience of British cities and an analysis of the damage at the Krupp works this spring.

A. The British "Baedeker" Raids

In Exeter, Norwich, and Canterbury a six-week period of air raids in the late spring of 1942 involved HE densities averaging 7 to 11 tons per square mile over the entire area within the administrative limits of these cities. The accompanying IB tonnage was relatively small.

Since it has been estimated that the current rate of RAF activity over the Ruhr yields about 12 tons per square mile per month over the entire built-up area, and since about half of this is HE, the Ruhr and British rates of attack are at least comparable. The primary differences are:

1. In the Ruhr this intensity of attack has already been maintained more than twice as long, and will probably continue for some months.

2. The whole industrial complexion and layout of Exeter, Norwich and Canterbury differ markedly from that of the Ruhr. The characteristic Ruhr types of heavy industry integration are lacking in these particular British towns; and although it is difficult to evaluate this difference in terms of vulnerability to bombing, the difference must nevertheless be recognized.

3. The British raids are already more than a year old. In the interval there have been further developments in defense tactics against air raids, in bombs and their use, in the protection of structures against damage, and in the organization of reconstruction activities. Also, the economic effects of physical damage may be greater in the Ruhr since that area is now more fully on a war-production basis than British cities were in early 1942. The process of conversion and stripping of non-essential activities has also gone further and the reserve margin of resources is thinner.

The economic damage caused in the Baedeker raids has been measured in terms of city working days lost. Absences immediately after major raids were 30 to 40 percent in the Baedeker towns, tapering off in a fortnight or so to a fairly stable level of 10 to 16[1] percent which persisted beyond the period of the inquiry. Damage to workplace appears to have been a somewhat more important cause of absence than all other factors such as damage to homes, damage to transit facilities, or "anxiety". To judge by the effects of these raids, a recurrence of such a scale of attack for some months could be expected to keep employment down at least 20 percent. It may be surmised that output would suffer rather more.

B. The Coventry Raid

Another basis of estimate in British experience is provided by the loss of output suffered in Coventry after a raid in which the Germans achieved a bomb density of approximately 7 or 8 tons per square mile. Industrial activity (as measured by an index of electric power consumption) was reduced immediately to 37 percent of normal. The somewhat higher intensity of Ruhr raids indicates that an immediate reduction to 30 percent of pre-raid output might fairly be assumed there.

Unless the Germans decide to disperse the industry of the Ruhr, we must expect they will make strenuous efforts to repair the damage of initial raids and to restore production. If the assumed projection of operations in the Ruhr is correct, the Germans will have about 30 days between raids to effect repairs in any given city. At Coventry, the average rate of recovery was roughly 2 percentage points per day. Considering the cumulative weight of attack in the Ruhr and the fact that neighboring areas will also be seriously damaged, it seems unlikely that the Germans can do better. At this rate, production in a Ruhr target area might recover to about 90 percent of its pre-raid level before the next raid.

It is likely, however, that the rate of recovery in each monthly recovery period is more rapid in the first few days after a raid than later. Much damage tends to be superficial; obstruction from rubble and dirt is easily removed; repair to transportation and power proceeds rapidly. Thus a mass of facilities that are not themselves vitally injured may be quickly restored to activity, while repairs to a smaller proportion of an area's capacity proceed at a far slower pace. If, for example, production recovers at the rate of 3 percentage points per day during the first 15 days following a raid, and at but 1 percentage point per day for the next 15 days, it is easily calculated that the average monthly rate of production during a period characterized by heavy monthly raids will be approximately 66 percent of normal.

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[1] The higher figure in each case applied to Exeter, which had more extensive fire damage than the other cities and is perhaps a better guide to Ruhr experience for that reason. The Germans used several times as much HE as IB in the Baedeker raids, whereas in current RAF attacks on the Ruhr nearly equal proportions are employed.

C. Effect of Essen Raids on the Krupp Works

Finally we may turn to what is known of actual Ruhr experience, relating primarily to the Krupp works in Essen. Three separate raids[1] and over 100 bomb hits were involved, which makes the sample not entirely inadequate in size, and the complex of operations at Krupp is representative of a dominant segment of Ruhr industry.[2]

Direct damage resulted in immediate curtailments of output ranging from zero to 80 percent in different departments. The variation is probably due mainly to chance. Considering indirect damage to plant utilities, drain on labor for clearance and repair, absenteeism from causes other than damage to works and the time necessary for restoration of full capacity, it appears that this series of raids occasioned an overall loss of about 2.4 months. This evaluation is based in part on parallel British experience.

The density of bomb hits on the Krupp works in each of the three raids was roughly 25 tons per square mile, or twice as great as can be expected over the average Ruhr industry district in the average current raid. The frequency of the Krupp raids (three in 30 days) is about three times what can be maintained over the average major Ruhr target city. In effect, the current (and prospective) rate of RAF attack on the Ruhr is such as to duplicate the bomb density of the three Krupp raids over the industrial areas of the Ruhr generally every six months. At current rates, the 1943 season of Ruhr bombing will have done this by the end of September. If the Krupp experience is indicative, the result should be about 2.4 months' loss of Ruhr industrial output. A loss of 2.4 months' output out of six represents a decline of 40 percent.

The incidence of this loss of output, however, is distributed over a long period, which means that some of the effect of any six months' attack will not be felt until long after the end of the six months. In the Krupp raids, the repair of plants was estimated to require as long as eight months in a few departments. Loss of time from

[1] 5-6 March, 12-13 March, and 3-4 April 1943.

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[2] Pre-raid activities as estimated by MEW include manufacture of the following finished and semi-finished products: gun mountings and ammunition (including fuzes) for heavy land A.A., torpedo tubes, air vessels, bombs, armor plate, forged drums for high-pressure boilers, diesel engines for heavy road transport, drop forgings, shafts, cranks, flywheels, bars, wheels, axles, rolls, seamless cylinders, plates, tires, wire, bronze, brass and aluminum castings, boilers, railway signals, rails including points, crossings, turntables, springs, surgical instruments. agricultural machinery, steel dentures (monopoly), gears, dredgers, pneumatic tools, centrifugal purifiers, bolts, screws, gauges, fire bricks, refractory materials, printing machinery, tank components. In addition, the surface works of two coal mines are on the property.

casualties and personal absenteeism in any locality as a whole would persist on a very small scale indefinitely, although this probably would not apply to the more essential war activities of the locality.

British experience of recovery after raids makes possible a rough estimate of (a) the extent to which production would decline by the end of September at current rates of attack, and (b) the average loss of production during six months of attacks at this rate. In both cases we assume the weight of attack (12 tons per square mile per month) and the total output loss (2.4 months) explained above.

Total loss may be analyzed as a compound of three elements:

(a) Loss of time from work (for all causes, including "work not available" and "personal reasons").

(b) The employment of productive labor in clearance and other repair work.

(c) Loss of efficiency of those at work.

British experience of recovery from raids of an intensity similar to those assumed for the Ruhr enables us to distribute loss of work time over the months following a heavy raid. Approximately 50 percent of the loss of time can be expected to occur in the first month, another 25 percent over the next three months, and the remaining 25 percent over the following twenty months.[1] For industries given priority in repairs a much smaller percentage of the loss would extend over three months.

Assuming this distribution of loss of work time to represent the distribution of loss of production, it can be shown that 27 percent of output would be lost, on the average, during six months of bombing, and that the rate of production at the end of such a period would be 31 percent under normal.[2]

There are two reasons to believe that both these figures are too low:

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[1] Percentages for individual months are secured by interpolation.

[2] Letting l. represent the percentage of total loss suffered in the first month following a raid, l_2 the percentage in the second month, etc., the cumulative percentage of loss suffered after n months of continuous raiding is

$$l_1 + l_2 + \cdots\cdots + ln = Ln$$

L_6 = 78 percent is the percentage of total loss suffered at the end of six months. The total loss from six months' attacks is 40 percent, and 78% x 40% = 31%. The average of

$$L_1, L_2, \ldots\ldots, L_6 = 68\%$$

is the average percentage of the total loss during six months of raiding, and 68% x 40% = 27%.

(a) They disregard the delayed incidence of bombings prior to the intensive 1943 campaign.

(b) The other two factors in production loss - reduced efficiency, and the use of productive labor for clearance and repair - tend to be much more highly concentrated in the first few weeks after a raid than does the loss of time.

It is likely, therefore, that at least 30 percent of "normal" production would be lost during the six months, and that production would decline by 35 percent by the end of September or by perhaps 30 percent in August. Prevention of recovery would, of course, entail continued bombing, but at a somewhat lower rate than in May and June.

D. Summary of Indications of Overall Production Loss

The three cases used as indications of the probable scale of production loss in the Ruhr leave much to be desired from the standpoint of statistical comparability and adequacy. It is significant, however, that all point to a degree of involuntary curtailment of the order of one-third. No more precise estimate seems attainable on the basis of present knowledge. This curtailment has perhaps already been attained in some industrial zones of the Ruhr, and should become generalized as the raids continue on a regular periodic basis.

The intensity of attack maintained this summer is such as to preclude complete recovery in the intervals between raids, and consequently leads to cumulative attrition of productive facilities. If and when the decision is made to divert some bomber strength from the Ruhr to other targets, a somewhat reduced intensity of attack should serve to keep Ruhr output well below 1942 levels.

The degree of involuntary and voluntary curtailment will certainly vary widely as between different types of industry in the Ruhr, according to their relative vulnerability and the importance attached to restoring them. Photo-reconnaissance at the Krupp works subsequent to raids on Essen this spring, for example, showed that no attempt had been made to repair certain important buildings. The abandonment of some damaged structures will tend to speed repairs on those deemed more essential. In general, facilities which are most easily repaired, vital to the war effort, and least capable of transfer elsewhere will claim priority of reconstruction.

These relative prospects in leading Ruhr industries will be examined in the subsequent section of this study.

VI. EFFECT ON AXIS WAR POTENTIAL

Previous sections have indicated the substantial damage already inflicted on Ruhr industrial and housing facilities and the further damage to be expected in the third quarter of 1943. By this fall about 30 percent of the population will have been dehoused, and industrial output reduced about a third, even in the absence of any deliberate evacuation.

General evacuation is unlikely, and there is at present no confirmation of reports that either labor or specific industrial equipment has been moved. In any case, however, normal output in the Ruhr cannot be maintained, and readjustments in German consumption and manufacturing processes will be necessary. The characteristics of Ruhr industries and their relation to the Axis war economy will determine policy.

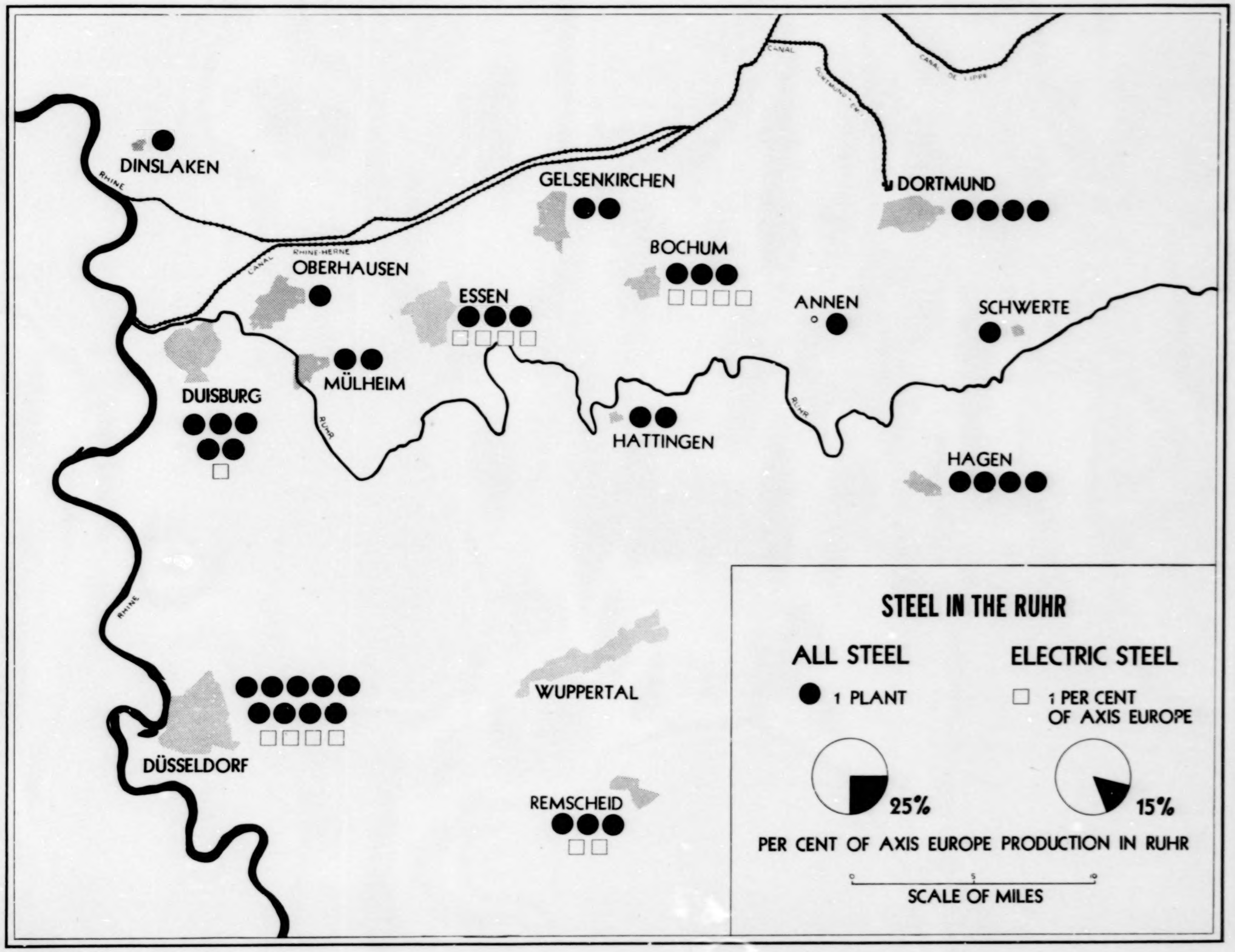
A. Position of the Ruhr in Axis Industry

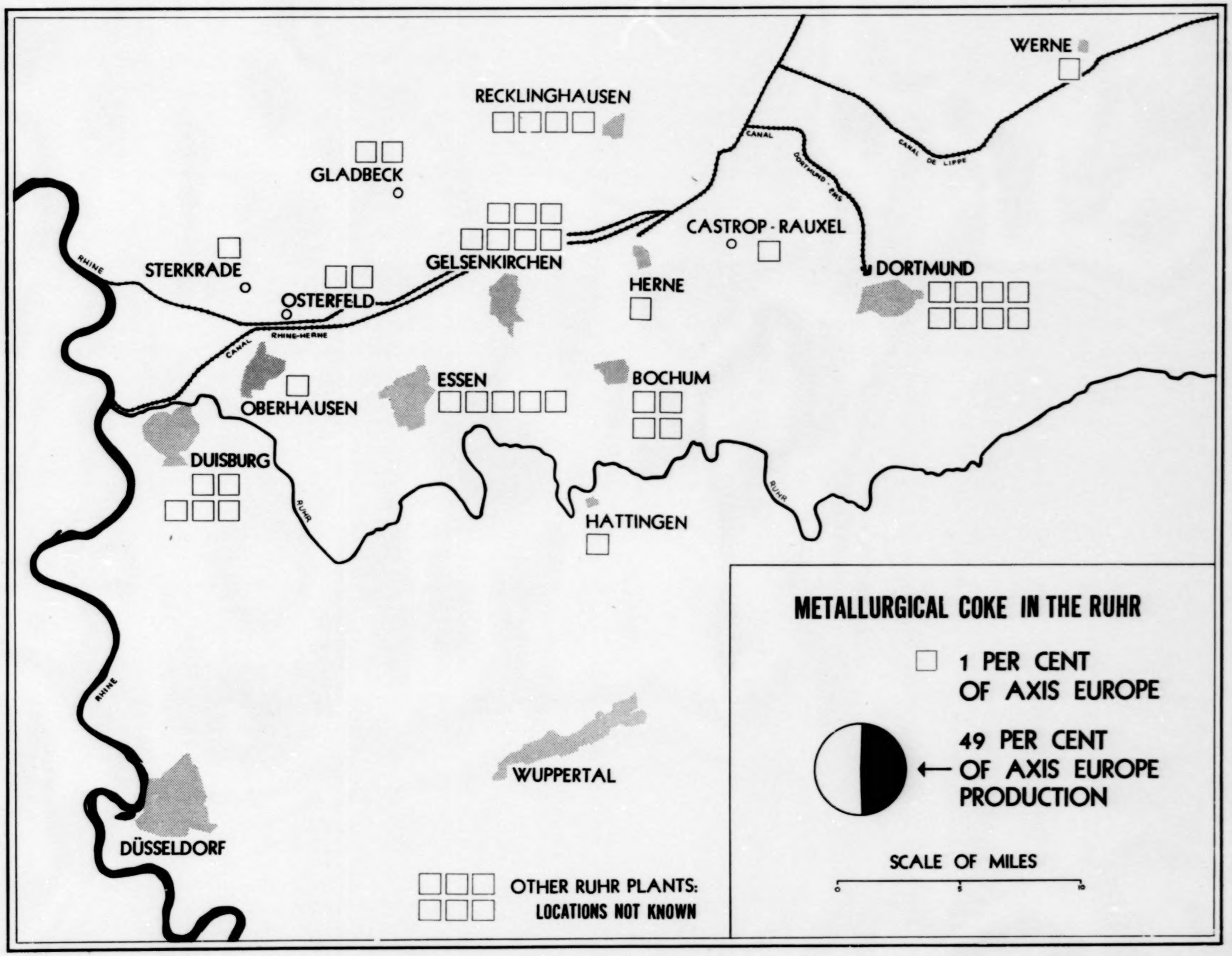
1. General. No other area in Europe can approach the Ruhr with respect to integration of raw materials, power, heavy industries, and finished products. Quantitatively and qualitatively its output is important to the war economy of the European Axis, not only for basic raw materials and industrial products, but also for direct output of military supplies.

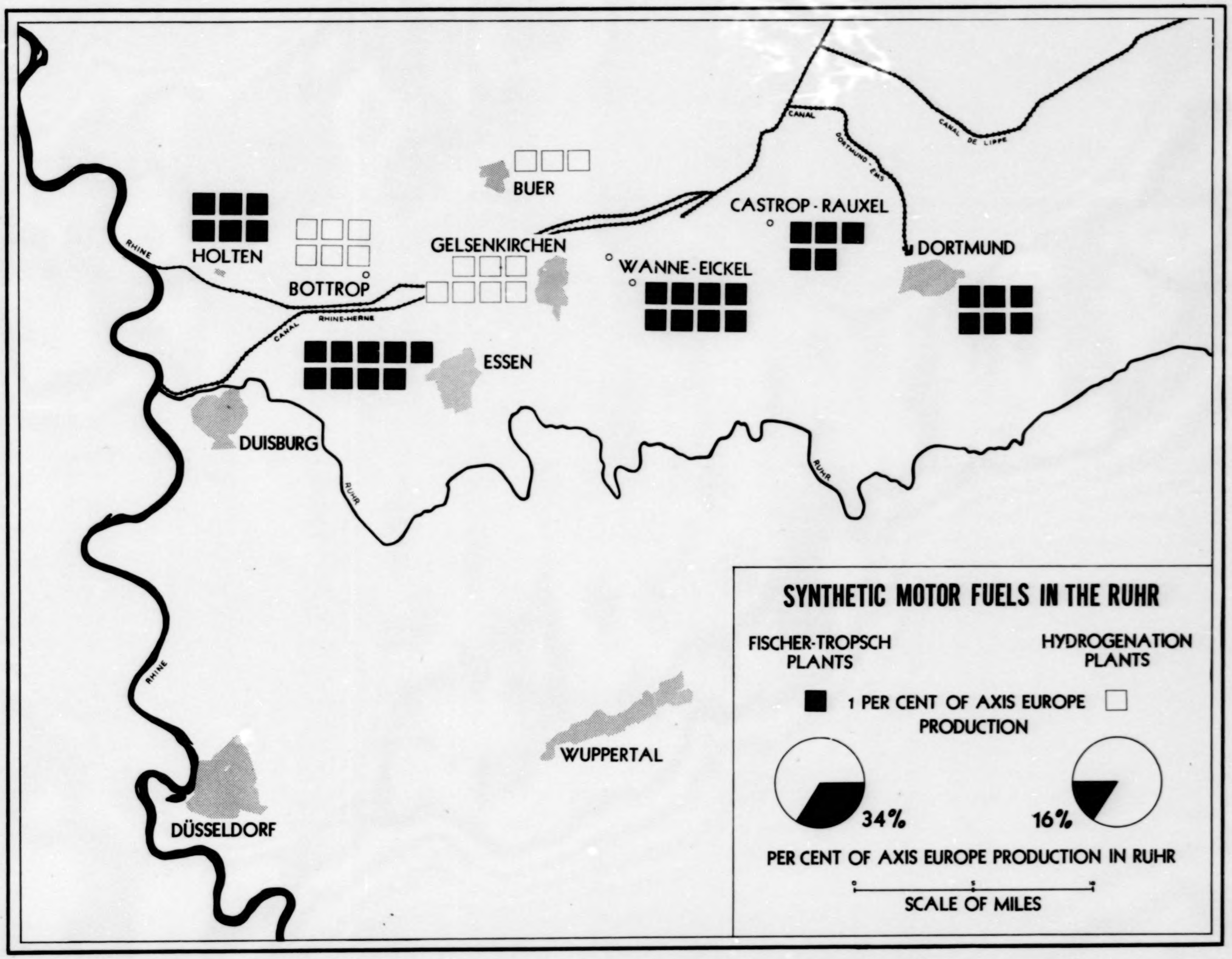
Table 4 lists the principal Ruhr industries with estimates of their relative contributions to total European Axis production. The Ruhr is responsible for one-quarter or more of the total Axis output of steel, synthetic rubber, synthetic oil, tungsten carbide, batteries, wire, pipes and tubes, machine tools, heavy machinery, coal and coke; for 30 percent or more of armor plate, engine parts, ammunition, artillery and guns. Qualitatively much of this production is even more significant. The Ruhr's high-quality (including electric) steel output, high-test gasoline capacity, hard coal and metallurgical coke production, for example, would be especially difficult to replace.

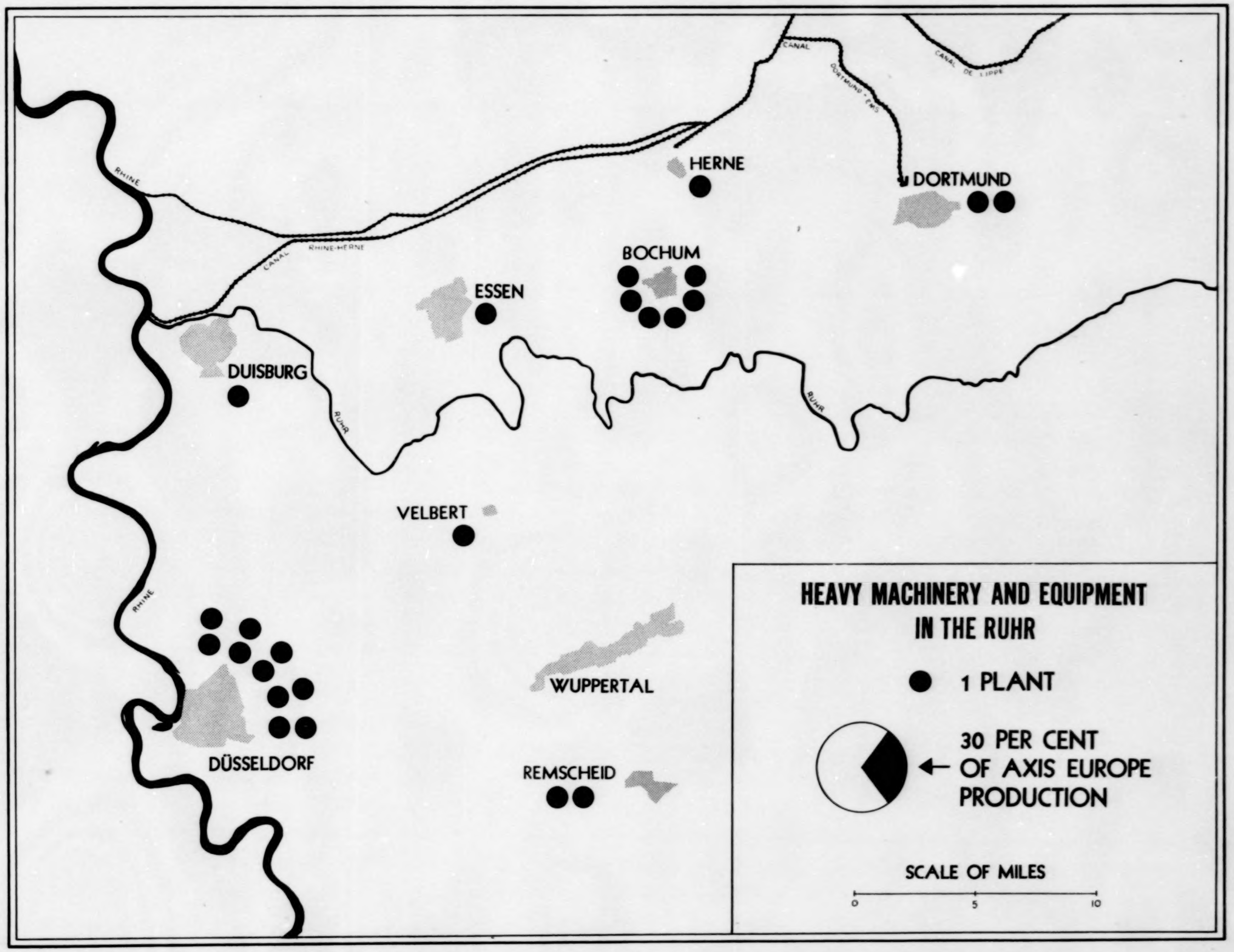
Further details on the concentration of certain types of plants in the Ruhr are shown in Figures 2-7.

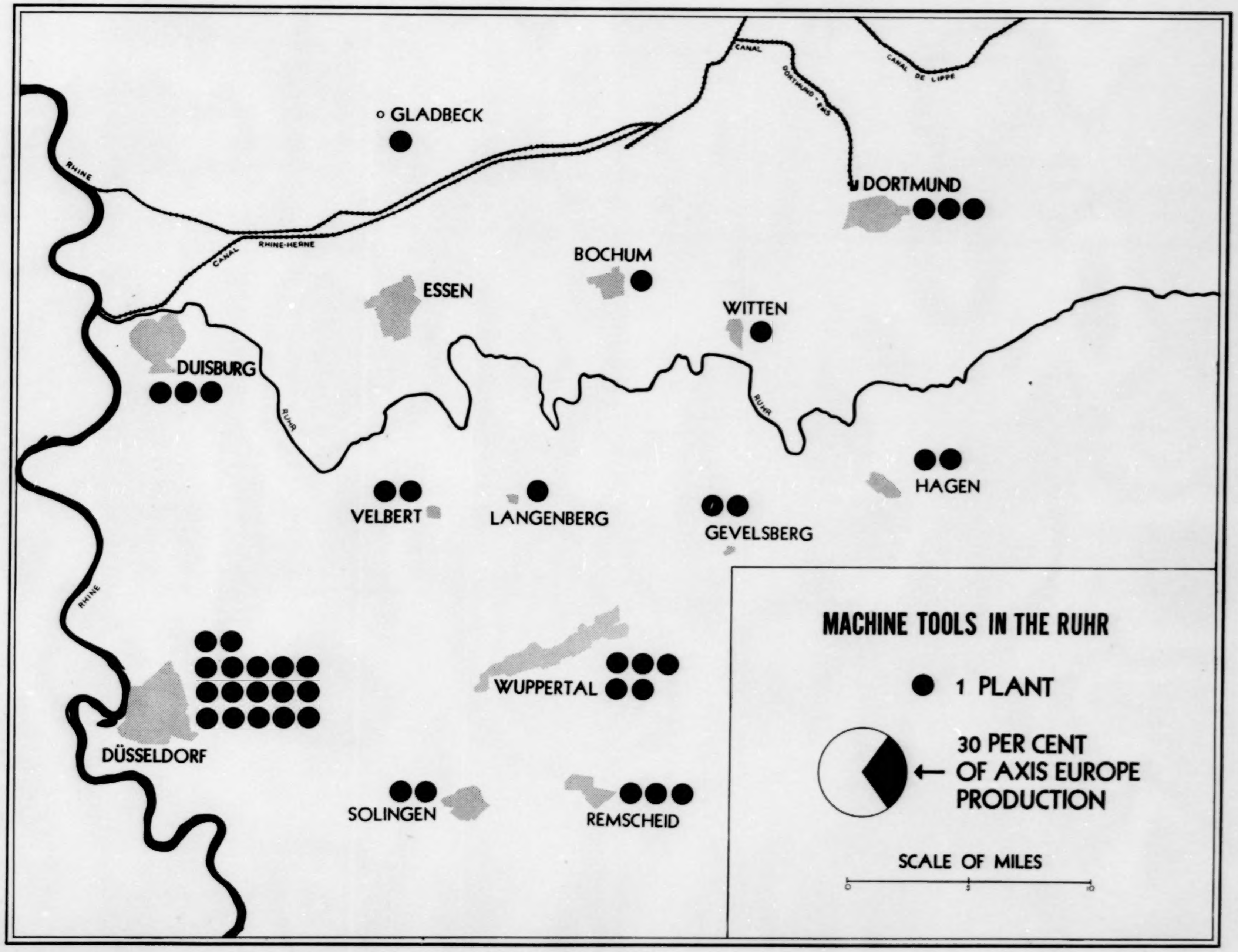
The significance of the Ruhr lies as much in the high degree of integration which the area has attained as in the contribution of specific industries to the Axis economy. Ruhr producers of end products rely heavily upon raw materials and semi-manufactured products made in the area. Carbon and quality steel for the machinery and armament industries of the Ruhr come from local steel plants. The cranes, rolling mills, presses and pumps of the steel and artillery plants are made, for the most part, within the Ruhr valley. The possible evacuation of Ruhr industries, therefore, must be considered in terms of the replacement of general industrial facilities and raw materials, as well as of specific end products.

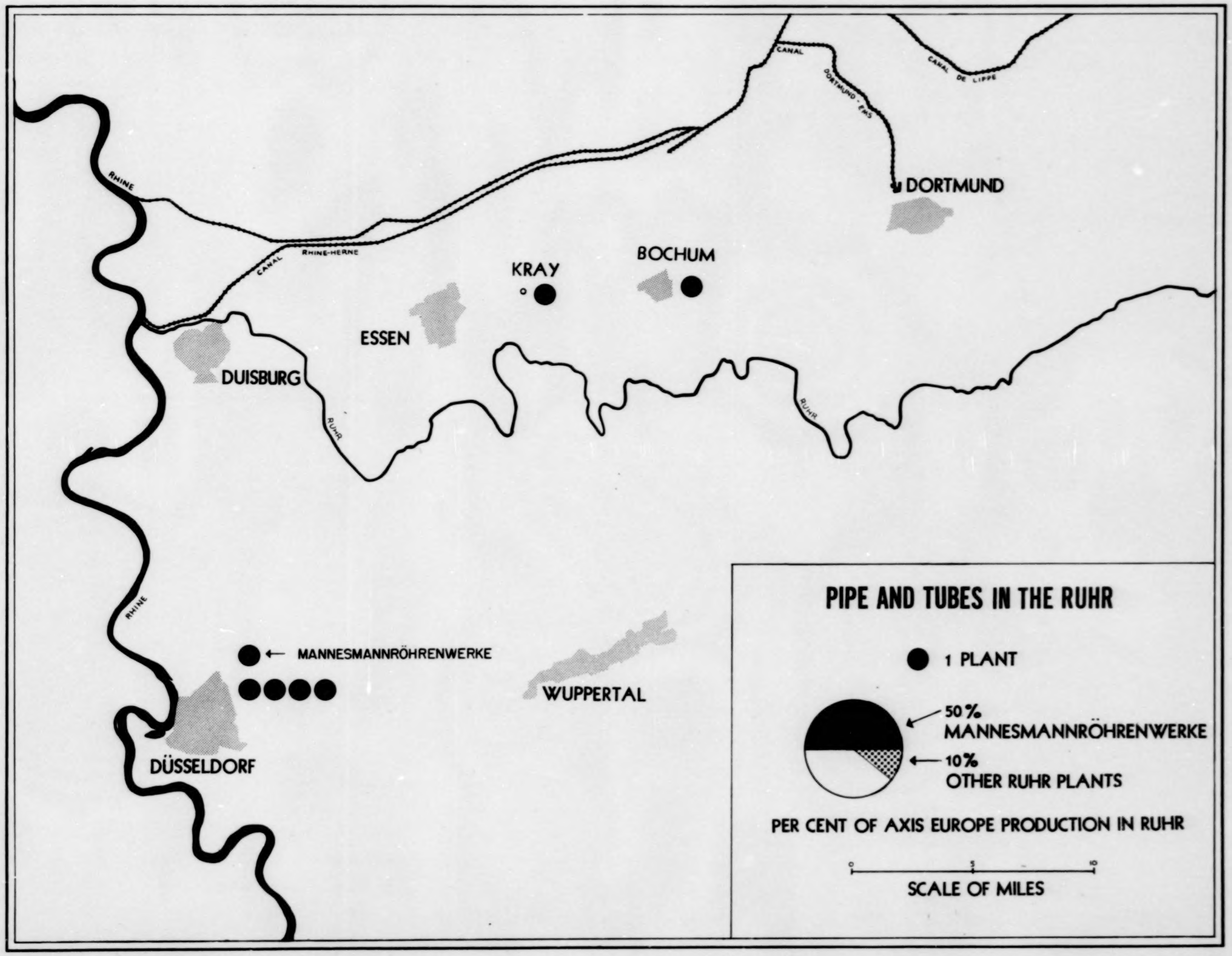

STEEL IN THE RUHR
ALL STEEL
● 1 PLANT
ELECTRIC STEEL
□ 1 PER CENT OF AXIS EUROPE
25%
15%
PER CENT OF AXIS EUROPE PRODUCTION IN RUHR
0
5
10
SCALE OF MILES
DINSLAKEN
GELSENKIRCHEN
DORTMUND
BOCHUM
OBERHAUSEN
ESSEN
ANNEN
SCHWERTE
MÜLHEIM
DUISBURG
HATTINGEN
HAGEN
WUPPERTAL
DÜSSELDORF
REMSCHEID
RHINE
RUHR
CANAL
RHINE-HERNE
DORTMUND-EMS
CANAL DE LIPPE


METALLURGICAL COKE IN THE RUHR
1 PER CENT OF AXIS EUROPE
49 PER CENT OF AXIS EUROPE PRODUCTION
SCALE OF MILES
0
5
10
OTHER RUHR PLANTS: LOCATIONS NOT KNOWN
WERNE
RECKLINGHAUSEN
GLADBECK
CANAL DE LIPPE
CANAL DORTMUND - EMS
CASTROP - RAUXEL
DORTMUND
STERKRADE
OSTERFELD
GELSENKIRCHEN
HERNE
CANAL RHINE-HERNE
RHINE
OBERHAUSEN
ESSEN
BOCHUM
DUISBURG
RUHR
HATTINGEN
WUPPERTAL
DÜSSELDORF


SYNTHETIC MOTOR FUELS IN THE RUHR
FISCHER-TROPSCH PLANTS
HYDROGENATION PLANTS
■ 1 PER CENT OF AXIS EUROPE PRODUCTION □
34%
16%
PER CENT OF AXIS EUROPE PRODUCTION IN RUHR
SCALE OF MILES
HOLTEN
BOTTROP
BUER
GELSENKIRCHEN
WANNE-EICKEL
CASTROP-RAUXEL
DORTMUND
ESSEN
DUISBURG
WUPPERTAL
DÜSSELDORF
RHINE
RUHR
CANAL RHINE-HERNE
CANAL DORTMUND-EMS
CANAL DE LIPPE


HEAVY MACHINERY AND EQUIPMENT IN THE RUHR
● 1 PLANT
30 PER CENT OF AXIS EUROPE PRODUCTION
SCALE OF MILES
0
5
10
CANAL
DORTMUND-EMS
CANAL DE LIPPE
HERNE
DORTMUND
RHINE
CANAL
RHINE-HERNE
BOCHUM
ESSEN
DUISBURG
RUHR
RUHR
VELBERT
RHINE
WUPPERTAL
DÜSSELDORF
REMSCHEID


MACHINE TOOLS IN THE RUHR
● 1 PLANT
30 PER CENT OF AXIS EUROPE PRODUCTION
SCALE OF MILES
0
5
10
GLADBECK
DORTMUND
BOCHUM
ESSEN
WITTEN
DUISBURG
VELBERT
LANGENBERG
GEVELSBERG
HAGEN
WUPPERTAL
DÜSSELDORF
SOLINGEN
REMSCHEID
RHINE
RUHR
CANAL RHINE-HERNE
CANAL DORTMUND-EMS
CANAL DE LIPPE


PIPE AND TUBES IN THE RUHR
● 1 PLANT
50% MANNESMANNRÖHRENWERKE
10% OTHER RUHR PLANTS
PER CENT OF AXIS EUROPE PRODUCTION IN RUHR
0
5
10
SCALE OF MILES
DORTMUND
BOCHUM
KRAY
ESSEN
DUISBURG
WUPPERTAL
DÜSSELDORF
MANNESMANNRÖHRENWERKE
RHINE
RUHR
CANAL RHINE-HERNE
CANAL DORTMUND-EMS
CANAL DE LIPPE

2. Power and Fuel. In 1942, 14 billion KWH were consumed in the Ruhr from a capacity of 4.5 million KW. This production and capacity constituted about one-fifth that of the Altreich. Most of the Ruhr capacity is contained in power plants located on the sites of the more important industrial facilities. The Ruhr system is normally almost self-sufficient, with small exports of power to the north and east largely offset by small imports in the south. Numerous interconnections exist by which local emergencies can be met, so it is unlikely that bomb damage to power facilities will have any substantial effect on production.

The Ruhr produces annually some 110 million tons of bituminous coal and 35 million tons of coke. The coal is of high quality and could not be completely replaced by coal of the same grade from other areas where mines have already been pushed beyond maximum efficiency. The metallurgical coke now produced barely covers the needs of the steel industry at present rates of activity. The German economy could not sustain the loss of Ruhr coal and coke for any length of time without curtailment in the general level of industrial activity and probably in military production as well.

3. Manufacturing

a. Combat munitions. The most significant Ruhr military products are engine parts (including gears, clutches, differentials, crank shafts, etc.) and armor plate. Krupp and the Kurbelwellenwerk (Reinbeck) alone account for 40 percent of German crankshaft requirements. These parts are essential for the maintenance of aircraft, tank, and truck output. Armor plate production in the Ruhr, particularly the output of Bochumer Verein, Krupp, and the Gutehoffnungshütte, constitutes roughly 60 percent of total Axis output. High quality steel (open hearth and electric furnace), stripping and rolling mills are required for the production of armor plate. The loss of Ruhr facilities would be a severe blow to the Axis war machine.

Ruhr tank production is concentrated in the Krupp works (Essen) and Rheinmetallborsig (Düsseldorf) and is of small significance to the Axis war effort. The Axis tank position is relatively easy and complete loss of Ruhr facilities would probably have little material effect upon military operations. A somewhat similar situation exists for trucks, as the Axis truck position is sufficiently flexible to withstand a ten percent production loss. One firm only (J.G. Schweitze, Düsseldorf) makes torpedo tubes. Its production is of relatively little significance.

The output of ammunition, artillery, and engines (principally tank engines) in the Ruhr is of much greater relative importance. Loss of tank engine facilities would have greater effect on tank strength than loss of the final assembly plants.

b. Heavy machinery and industrial equipment. All types of machinery are produced in the Ruhr, including cranes, pumps, presses, rolling mills, turbines, and mining and construction machinery. Except possibly for the area around Berlin, the Ruhr represents the greatest single concentration of such production facilities in Axis Europe. The same is true for machine tool production. The manufacture of boilers and allied equipment and transportation equipment in this area, on the other hand, constitutes a rather small percentage of Axis output and is not of great significance in itself.

Perhaps the most important general industrial item made in the Ruhr is pipes and tubes, which are basic in the maintenance of all types of industrial installations, The Ruhr accounts for 60 percent of Axis production, with the Mannesmannröhrenwerk in Düsseldorf as the principal manufacturer. The production of wire, cables, batteries, ovens, and furnaces is in each case a significant portion of Axis output. The Felton and Guilleaume plant at Duisburg makes 20 percent of all German cables and the Accumulatoren Fabrik at Hagen produces 25 to 30 percent of all German batteries and 60 percent of all U-boat batteries. Oven and furnaces production is also important, since Kupperbusch (Gelsenkirchen) is the largest manufacturer in Germany, and, with the Dortmund plant of Brown-Boveri, accounts for 35 percent of all German furnace production. The Mannesmann plant at Witten is notable for making all Fischer-Tropsch contact ovens.

c. Iron and steel. Fundamental to the entire industrial development of the Ruhr is its steel industry. Before the current heavy bombings, Ruhr steel ingot capacity was estimated at 14 million tons, or 25 percent of the entire capacity of Axis Europe. This steel capacity is more than half the German total, and greater than that of any other single area in Europe. The nature of the steel produced is of even greater importance. The bulk of Axis quality steel is manufactured in the Ruhr, which contains 15 percent (600,000 tons) of Axis electric furnace capacity and well over half of total Axis open hearth capacity. Moreover, almost all the big Ruhr steel plants contain substantial amounts of finishing and processing equipment (rolling mills, presses, forge and machine shops, foundries, etc.) as well as machinery for making munitions and engine parts.

Vertical integration has been carried far in the Ruhr steel industry, assisted by the proximity of large supplies of coal, coke, and iron ore. Coal mine shafts are, in some cases, within 100 yards of the pig iron and steel furnaces. Coke ovens and coke by-product equipment are actually on the plant sites. The entire steel-making process can be carried on with almost no resort to resources outside the Ruhr area.

Vereinigte Stahlwerke, with its five plants, (at Bochum, Hamborn-Bruckhausen, Ruhrort-Meiderich, Duisburg, and Witten) controls half of total Ruhr steel capacity.

Krupp (Essen and Essen-Borbech), Hoesch (Dortmund), Klockner (Düsseldorf), and Mannesmann (Gelsenkirchen) account for most of the remainder. Nearly 40 percent of German electric steel capacity is divided (almost equally) between steel plants at Bochum, Essen, and Düsseldorf. The remainder of the Ruhr electric steel capacity is at Remscheid, Duisburg, and Hagen.

d. Other industries. Among the industries not already considered, tungsten carbide, synthetic oil, and rubber can be considered as the most important to the Axis economy.

Some 75 percent of Axis tungsten carbide production takes place at the Krupp works at Essen. The use of tungsten carbide in machine tool cutting tips and armor-piercing bullet cores makes its continued manufacture essential to the production of war material.

About one-quarter of Axis synthetic oil capacity is concentrated in the Ruhr. This amount includes almost one-half of total Fischer-Tropsch capacity, which supplies a very high grade motor fuel. The Axis cannot afford to lose any oil production, and the qualitative aspects of the Ruhr output makes its continuance even more essential to military operations. One of the two largest synthetic rubber plants in Europe, Chemische Werke, is located at Hüls. The present Axis rubber situation, with blockade running from the Far East curtailed, makes it important that synthetic production should not be interrupted or reduced.

The chemical industry of the Ruhr, aside from coke by-products, is chiefly concerned with sulphuric acid and synthetic nitrogen production. The Ruhr output is not of great significance for the Axis economy as a whole. There are also a number of small metal-working plants but their output is not large.

B. Evacuation of Industries From the Ruhr

1. Prospects for Evacuation of Specific Industries. It has already been indicated that any evacuation or abandonment of Ruhr industries as a result of bomb damage is likely to be highly selective. The policy as to maintenance of any particular industry in the Ruhr will depend not only upon the importance of its output to the Axis war economy, but also upon its vulnerability to air attack, the availability of surplus facilities elsewhere and the transferability of such equipment and manpower as would have to be moved from the Ruhr. A brief appraisal of these factors follows.

a. Vulnerability. In general, the types of industrial facilities found in the Ruhr are not highly susceptible either to blast or fire damage. Areas with bomb and shell loading, synthetic fiber or woodworking plants would show much greater destruction.

Table 4. THE IMPORTANCE OF RUHR INDUSTRY IN AXIS EUROPE

Industry	Percent of Total Axis Output	Most Important Plant
MILITARY ITEMS		
Armorplate	60	Bochumer Verein, Bochum
Engine parts	45*	Krupp, Essen
Ammunition	40*	Krupp, Essen
Artillery and guns	30*	Bochumer Verein, Bochum
Trucks	10	Krupp, Essen
Tanks	6	Krupp, Essen
Military engines	5*	Krupp, Essen
Torpedo tubes	5*	J. G. Schweitze, Düsseldorf
(* Very rough estimate)		
MACHINERY		
Heavy machinery	30	Demag, Duisburg
Machine tools	30	Schiess, Düsseldorf
Transportation equipment	10	Maschinenbau u. Bahnbedarf, Dortmund
Boilers	5	Ver. Kesselwerk, Düsseldorf
INDUSTRIAL EQUIPMENT		
Pipes and tubes	60	Mannesmannröhrenwerk, Düsseldorf
Batteries	25	Akkumulatoren Fabrik, Hagen
Cables	20	Felton u. Guilleaume, Duisburg
Ovens and furnaces	20	F. Kuppersbusch, Gelsenkirchen
Ball bearings	3	Jaeger, Wuppertal-Eberfeld
STEEL		
Total steel	25	Thyssen, Hamborn-Bruckhausen
Electric steel	15	Bochumer Verein, Bochem
MISCELLANEOUS		
Tungsten Carbide	75	Krupp, Essen
Synthetic rubber	30	Chemische Werke, Hüls
Synthetic motor fuel	26	Gelsenberg, Gelsenkirchen
Chemicals	10	A.G. für Teerverwertung, Duisburg
Metal working	3	Duisburger Kupferhütte, Duisburg
COAL (hard coal equivalent)	25	
COKE	50	
ELECTRIC POWER	20	

In Table 5, the most important Ruhr industries are ranked according to their susceptibility to HE and IB. In the case of IB damage, the national rating schedule for occupancy combustibility was used. The scale ranges from one to five, with one for non-hazardous, non-combustible products and five for the most hazardous and combustible products and processes. A similar scale was set up for buildings and the two ratings combined with appropriate weights to give an index of susceptibility to IB attack.

b. Relative evacuation prospects. Table 6 lists the major Ruhr industries with some indications as to whether they would be wholly or partially evacuated, and where they might be relocated. The likelihood of evacuation has been based upon the relative importance of each industry to the Axis, the existence of idle or easily expandible facilities elsewhere, the relative vulnerability of the industry to air attack, and the physical difficulty of moving its equipment. In general, this last aspect is paramount. At least two years would be required to move and put into operation the heavy equipment of the Ruhr steel, machinery, and armament industries. The most probable solution appears to be that the Germans will move certain lighter types of equipment if they can and use it to expand existing facilities already in existence.

The only industries for which complete evacuation of certain plants, at least, is probable are engine parts, pipes and tubes, batteries, ovens and furnaces, and parts of the steel industry. The latter has special problems which require individual attention. The others produce a share in total Axis output sufficiently large and are in general sufficiently easy to move so that an attempt would be made to evacuate them. Other important industries, such as tungsten carbide, can be rebuilt easily and quickly (in six months) and probably would not be evacuated.

Excess steel capacity now exists, but it is mainly in France and Belgium, which are as accessible to bombing as the Ruhr. Furthermore, the greater part of excess capacity there is basic Bessemer and not high quality open-hearth and electric-furnace steel. The Germans would probably prefer to expand quality-steel output in Eastern areas rather than attempt to expand French and Belgian production. If the Ruhr steel industry were eliminated, and the French and Belgian excess capacity disregarded, the Axis would have some 31 million tons of effective steel capacity. By reducing industrial requirements for railroad equipment (especially track and structures) buildings and works and other items, it is estimated that the Germans could get along on an annual steel supply of 35 million tons, as against the 42 million tons they are now believed to have. They might manage on less if military production were reduced, or deterioration of plant and equipment were allowed to take place as it has in Russia.

American experience in the shifting and expansion of steel plants suggests that the evacuation and/or construction of several million tons of steel capacity and finishing equipment would take at least two years. The following table indicates the length of time required to construct various types of equipment for a steel-ingot plant of 690,000 tons capacity, producing 586,000 tons of relatively simple semi-finished steel products and coke by-products.

Facilities	Months Required to set up
Blast furnaces, coke plant, raw materials handling	7
Open hearth furnaces (3)	10
Electric furnace	10
Blooming mill, soaking pits, plate mill	10
Structural mill	10
Merchant mill	11
Alloy finishing department	11

Two years were required to construct another plant of 1.3 million tons capacity, with a wide variety of finishing equipment (although not on the scale of the Ruhr plants). Eight thousand men worked two ten-hour shifts six days a week during the two year period. Furthermore, the dismantling of steel plants alone cannot be accomplished in less than six months.

At the outside, Germany would not try to move more than 3 or 4 million tons of quality steel capacity from the Ruhr. The difficulties of moving steel plants are so great, however, that she may only evacuate finishing and processing equipment to existing plants. Some 30 percent of existing Axis electric steel capacity, it may be noted, is in Italy.

c. Areas of relocation. Although no other area in Europe can compete with the Ruhr, certain areas are known to be undergoing industrial expansion. Upper Silesia is perhaps the most plausible site for relocation of Ruhr industries. The area includes iron and coal mines, the output of which could be expanded, and is reported currently to be undergoing expansion.

The Linz-Wiener Neustadt area is another possibility. Although it is principally concerned with metal working, it is located near iron and coal mines. Also, it contains many of the plants of the Goering works.

A vital steel, armament, and motor-vehicle center has already grown up around Prague and Pilsen. The plants of Skoda, Poldi, and

Witkovice are similar to the large steel and armament works of the Ruhr. Equipment from the Ruhr steel and armament plants might well be moved here to assist in expansion of output.

Scattered reports claim great industrial expansion in various parts of Hungary, Austria, Czechoslovakia, and Poland. An area such as one of the three mentioned above is more likely to be chosen, however, as duplicating to some extent the raw material situation in the Ruhr. Whatever area is selected will introduce transportation problems even after evacuation has taken place. Coal and coke will have to be sent from the Ruhr itself, and iron ore from Siegerland, France, and Belgium will have a longer journey.

2. Overall Problems of Evacuation

a. Russian experience. The physical problem of the evacuation of a heavily industrialized area such as the Ruhr is one of enormous magnitude. Russian experience in moving factories from the Ukraine to the Urals is of interest here, although not entirely parallel to the situation in which the Germans find themselves with respect to the Ruhr. So far as is known, there has been no advance large-scale plan for a Ruhr evacuation. The Soviet evacuation, on the other hand, was carried out according to a careful plan drawn up so long in advance that new plants built in the Urals were designed to receive particular items of equipment from the Ukraine.

During the Soviet evacuation 42 plants were successfully moved in a period of 4 to 9 months. Serious obstacles were encountered throughout the process. All equipment was shipped to certain points of redistribution, where various delays and complications of organization resulted in the loss of considerable equipment through exposure. Other difficulties arose from the re-establishment of plants in inappropriate buildings. A conservative estimate of the Soviet evacuation indicates that the following plants were safely removed:

	Number
Armaments	7
Munitions	3
Electrical equipment	5
Chemical	3
Heavy Machinery	5
Medium Machinery	2
Machine Tool	2
Tank	3
Rubber	3
Aviation	9
TOTAL	42

Even with plans laid long in advance and a dire shortage of steel, it is noteworthy that the Russians evacuated little or no basic steel capacity.

Table 5. RELATIVE VULNERABILITY OF SELECTED TYPES OF INDUSTRIAL PLANTS TO HE AND IB ATTACK

	Vulnerability[1] to		
Industry	HE	IB (U.S.Nat'l Rating Schedule)	Comments
A. Low vulnerability:			
Armor plate........	1	1	small incidental damage.
Artillery..........	1	1	
Bailers............	1	1	small incidental damage.
Pipes and tubes....	1	1	small incidental damage.
Steel..............	1	1	small incidental damage.
Electric power plants..........	1	1	usually small in area, but with highly vulnerable vital spots.
Coke plants........	2	1	very heavy equipment.
Mfg. of ovens......	2	1	
B. Medium vulnerability:			
Coke by-products...	2	2	some equipment highly vulnerable.
Machinery..........	2	1½	heavy machinery.
Machine tools......	2	2	incidental damage may be high, i.e., through dust and jarring.
Tanks-trucks.......	2	1½	
Torpedoes and tubes	2	1½	
Cables.............	2	(1 bare (3 insulated	
Gas plants.........	2	2	
Batteries..........	2	2	
Aircraft assembly..	2	2	
Engines and parts..	2	2	high incidental damage possible.

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1. HE ratings on arbitrary scale (1 = Poor, 2 = Fair, 3 = Good); IB ratings based on national rating schedule for occupancy (ratings 1 to 5) combined with a similar rating for structural fire hazard.

Table 5. RELATIVE VULNERABILITY OF SELECTED TYPES OF INDUSTRIAL PLANTS TO HE AND IB ATTACK
(continued)

Industry	Vulnerability[1] to HE	Vulnerability[1] to IB (U.S.Nat'l Rating Schedule)	Comments
B. Medium vulnerability:			
Electrical engineering	2	2	high incidental damage possible
Bearings..............	3	2	high incidental damage possible
Synthetic rubber......	2	2	
Synthetic oil Fischer-Tropsch....	3	2	
C. High vulnerability:			
Synthetic oil (hydrogenation)....	3	4	
Synthetic fibres......	3	4	
Flammable chemicals...	3	4	
Dwellings.............	3	4	

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[1] HE ratings on arbitrary scale (1 = Poor, 2 = Fair, 3 = Good); IB ratings based on national rating schedule for occupancy (ratings 1 to 5) combined with a similar rating for structural fire hazard.

Table 6. EVACUATION PROSPECTS FOR PRINCIPAL RUHR INDUSTRIES

Product	Possibility of complete evacuation	Possibility of partial evacuation	Probable area of relocation	Location of Existing Excess Capacity
Tanks	no	Molds and some machinery	Berlin area	Existing facilities could be expanded
Ammunition	no	Machine tools and press	Central German, Skoda, Poland	
Engine parts	yes		Berlin area	
Torpedo tubes, etc.	no			
Armor plate		yes	(see steel)	
Trucks	no		Brandenburg, Berlin, Frankfort	Brandenburg and Frankfort
Heavy machinery		yes	Berlin area	
Machine tools		yes	Berlin, Leipzig, Dresden	
Boilers	no			
Transportation equipment	no			
Pipes and tubes	yes		Bielefeld, Brackwede, Leipzig	
Wire	no	yes		
Ball bearings	no	equipment for making heavy bearings	Schweinfurt	

Table 6 (Cont'd.)

Product	Possibility of complete evacuation	Possibility of partial evacuation	Probable area of relocation	Location of Existing Excess Capacity
Batteries	yes		Stuttgart, Vienna, Berlin	
Cables	no	yes		Milan
Ovens and furnaces	yes		Berlin area	
Steel	no	To the extent of 4 million tons; finishing and processing equipment in any case	Upper Silesia, France, Belgium, Pilsen, Austria, Witkovice	
Synthetic rubber	no	yes	Schkopau (Silesia or Bruex)	Schkopau (under construction)
Synthetic oil	no	yes	To existing installation near coal fields in Central Germany, Sudetenland, Eastern Germany	
Chemicals	no			
Metal working	no			
Tungsten carbide	no		Reutte (Tyrol)	Existing facilities could be expanded
Coal	no	no		Expansion in Upper Silesia and Poland might replace about 1/3 of Ruhr production
Coke	no	no		

b. Manpower. The manpower situation in Germany is sufficiently tight so that reserves of skilled and unskilled labor do not exist. If Ruhr industries are to be moved to other areas, or industries in these areas expanded, sufficient labor to carry on additional production will not be available in these areas. In other words, the transfer of Ruhr production involves at least a corresponding transfer of Ruhr labor. In industries where surplus plant capacity already exists elsewhere, its substitution for Ruhr capacity is likely to depend on the shifting of manpower from the Ruhr.

The problems of moving labor from the Ruhr are those of any mass resettlement: The provision of transportation, housing, community services, and the like. Historically most population movements of this sort have been attended with many difficulties. In the case of Germany, the strain on transportation and housing facilities would be an important cost of such a move. It should be noted, however, that only a single movement of personnel would be involved rather than a permanent commitment of transport resources; and that the rehousing of many of these workers is a problem that must be faced whether they leave the Ruhr or not.

At present there is no reliable evidence of any migration from the Ruhr.

c. Transportation. Although the Axis transportation system has thus far adequately withstood the strains placed upon it, transport may become an overall limiting factor in the German war effort under certain conditions, such as the establishment of a two-front war. Evacuation of Ruhr industry, however, particularly on the scale which seems likely, can probably be handled without great difficulty. A more important consideration is the long-run strain which may be expected to occur after evacuation and the expansion of industry in other areas has taken place. Decentralization of some of the Ruhr industries may be expected to impose greater strain on transport eventually, and especially to introduce congestion at the eastern railroad junctions which are now used primarily for military traffic to the Eastern front.

C. Strategic Evaluation

If the Ruhr can be bombed to such effect that substantial evacuation of industry takes place, Germany will suffer immediate and permanent loss of economic potential. The main effect on military strength will be felt only after a considerable interval.

1. Loss of Economic Potential. Even if partial evacuation of Ruhr industries takes place, and some production of coal, coke, and steel is continued in the Ruhr under heavy bombing, probably a third of the Ruhr industrial output will be lost to Germany for at least a year. Some industries, such as tungsten carbide, wire, engine parts, cables, batteries could be relocated or rebuilt in less than a year, but in general the replacement of Ruhr output elsewhere could not be expected within that time.

Within two years, a good many Ruhr industries could be re-established in other areas, or existing plants could be expanded with the assistance of Ruhr equipment. A fundamental limiting factor, however, is the impossibility of replacing the Ruhr coal and coke output and the difficulty of replacing basic steel capacity. The latter could not be done in two years. In addition, the highly integrated and self-contained industrial facilities of the Ruhr as a whole could not be replaced in any period for which the war is likely to last. A serious continuing burden on transport will result from the geographical split-up of the industrial complex which must continue to be based in part on Ruhr fuel and materials.

Even if the difficulties of evacuation and of re-organizing production in other European areas are accomplished in one or two years, the German economic potential will be reduced by the loss of the Ruhr. The Axis economy will be forced to operate at a lower level. Industries in other areas are bound to feel the reduction in output of Ruhr raw materials, such as coal and coke, and any curtailment of the industrial output of component parts (engine parts, pipes and tubes etc.) will have an effect far beyond the limits of the Ruhr valley. Loss of basic steel, machinery, and machine tool production will necessitate greater depreciation of capital equipment. Quantitatively, this reduction cannot be estimated, but it is probably substantial.

2. Effect on Military Operations. The loss of much of the Ruhr output would have no immediate effect on military capabilities. The curtailment of coal, coke, steel, and even armament production would make itself felt fairly gradually by a process of attrition over some months. Stocks of heavy military equipment are also probably of sufficient size to maintain first-line strength over this period.

The knowledge that basic industrial capacity will be reduced, however, may prove to be an overall limiting factor in plans both for immediate and future operations. The Germans may be expected to husband their stocks with care, and possibly to curtail present production and operations if they can, although supplies on hand do not necessitate this step at once.

The loss of certain products, however, may be expected to have a more immediate effect. The most significant of these is synthetic oil. The oil situation is tight and may already be an overall limiting factor on plans for future military operations. It would take at least a year to move or rebuild the synthetic oil plants in the Ruhr, or even to expand existing oil plants with salvaged parts. The loss of the Ruhr output, particularly because of its high quality, might begin to hamper military activity within a matter of months.

Within a year some qualitative deterioration in armor plate would probably be apparent and there would be difficulty in maintaining first-line strength in military vehicles and requisite stocks of ammunition. Certainly, military operations could not be greatly intensified during this period without occasioning shortages; and general qualitative deterioration of equipment might be expected.

In the long run, present military production could probably be maintained, even with the reduction of the operating level of the Axis economy, but only at the expense of severe restriction of the civilian and industrial economy and trenching on capital by undermaintaining present industrial equipment. This situation is not one which would permit the expansion of offensive military operations. but it would permit maintaining a strong defense for an indefinite period.